PB80-212780

Analysis of Options to Limit Air Quality Degradation Due to Misuse of Leaded Gasoline in Cars Equipped With Catalytic Converters

Institute for Defense Analyses
Arlington, VA

Prepared for

Environmental Protection Agency
Washington, DC

Oct 79

U.S. Department of Commerce
National Technical Information Service
NTIS.

P880-212780
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IDA PAPER P-1426

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PROGRAM ANALYSIS DIVISION

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IDA Log No. HQ 79-21847

The work reported in this document was conducted under Contract No. EPA68-01-5150 for the Environmental Protection Agency. The publication of this IDA Paper does not indicate endorsement by the Environmental Protection Agency nor should the contents be construed as reflecting the official position of that agency.

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STANDARD TITLE PAGE FOR TECHNICAL REPORTS	1. Report No.	2. Govt. Accession No.	3. PB 80 212780

4. Title and Subtitle ANALYSIS OF OPTIONS TO LIMIT AIR QUALITY DEGRADATION DUE TO MISUSE OF LEADED GASOLINE IN CARS EQUIPPED WITH CATALYTIC CONVERTERS	5. October 1979 6. Performing Organization Code
7. Author(s) D. Dacy, P. Cutchis, R. Kuenne, J. Magnin, R. Oliver	8. Performing Organization Rept. No. IDA Paper P-1426
9. Performing Organization Name and Address Institute for Defense Analyses 400 Army-Navy Drive Arlington, VA 22202	10. Project/Task/Work Unit No. 11. Contract/Grant No. EPA68-01-5150
12. Sponsoring Agency Name and Address United States Environmental Protection Agency Washington, DC 20460	13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. Supplementary Notes
None

16. Abstracts
In this study the authors analyze three short-term and eight intermediate-term options to limit the use of leaded gasoline in cars equipped with catalytic converters. The short-term options analyzed are (1) mandated price differential between leaded and unleaded gasoline, (2) temporary suspension of ban on MMT, and (3) increased lead use in leaded gasoline. The intermediate-term options analyzed are (1) delay in introducing the three-way catalytic converter, (2) tax-subsidy schemes, (3) closing down self-service stations, (4) federal law against misfueling, (5) inspection-maintenance programs, (6) public relations program, (7) gasoline rationing, and (8) use of additives and blending materials to increase supply of unleaded gasoline.

17. Key Words and Document Analysis. 17a. Descriptors
Misfueling
Fuel-switching
Poisoning of catalytic converters
catalyst destruction

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Distribution Statement	19. Security Class (This Report)	21. No. of Pages
This document has been approved for public release.	UNCLASSIFIED	
	20. Security Class (This Page) UNCLASSIFIED	22. Price

USCOMM-DC 65002-P70

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Contract No. EPA68-01-5150

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FOREWORD

This paper was written almost entirely in May and June of 1979 under Environmental Protection Agency Contract No. 68-01-5150. At the time there was a gasoline shortage (particularly in unleaded gasoline) which arose suddenly in California and spread throughout most of the United States. The manifestations of the shortage were queueing for gasoline, rapid rise in prices, compression of the price differential between leaded and unleaded gasoline, and compression of the average prices charged at self-service and full-service stations. The shortage virtually disappeared in August 1979.

Even before the shortage became evident, officials at the EPA were concerned that the price differential between leaded and unleaded gasoline would entice some motorists to use the cheaper leaded gasoline in cars equipped with catalytic converters (a practice called "misfueling"), thereby damaging the catalysts and posing a threat to air quality. With the onset of the shortage, the threat to air quality was greatly increased due to misfueling aggravated by the unavailability of unleaded gasoline. Restoration of the gasoline supply-demand balance has not removed the potential problem, only its immediacy. It could become critical again. Most of the options discussed in this paper, therefore, will be of interest for several years.

After this study was prepared additional information on the use of methylcyclopentadienyl manganese tricarbonyl (MMT) was obtained by the EPA. Ethyl Corporation, the manufacturer of MMT,

had done a study indicating that a suspension of the ban on the manganese additive would permit a potential shift in production toward unleaded gasoline of up to 340,000 barrels per day. A telephone survey by the EPA in the summer of 1979 revealed that many gasoline manufacturers were not using MMT and others were not using it in the concentration allowed. As a result the estimate of increased production of unleaded gasoline was lowered to 130,000 barrels per day.* While our calculations of the benefits and costs of using MMT were never based on the Ethyl Corporation estimate, the discussion of this issue on pages 14-20 of this study should be read with the new information in mind.

*Memorandum from Joan Z. Bernstein, Acting Assistant Administrator for Enforcement, to the Administrator (undated).

SUMMARY

Misfueling is the practice of some motorists to use leaded gasoline in cars equipped with catalytic converters. The three principal reasons for misfueling are (1) leaded gasoline is cheaper than unleaded gasoline, (2) unavailability of unleaded gasoline, and (3) the perceived superior performance of leaded gasoline. Eventually, the use of leaded gasoline will poison the catalyst so that the converter will no longer be an effective device to protect air quality. If the social goal to be achieved is environmental protection, emphasis on action to prevent misfueling, *per se*, could be misplaced. Whether a particular policy is consistent with the desired goal depends upon the context in which it is to operate.

For the summer of 1979 the context was one of shortage of gasoline in the United States and, particularly, of unleaded gasoline. Much attention has been given to the policy option of compressing the price differential between unleaded and leaded gasoline under the assumption that such an action would induce previous misfuelers to switch back to unleaded gasoline. In a period of shortage this reswitching would exacerbate the shortage of unleaded gasoline and push other motorists to misfuel due to the increased unavailability of unleaded gasoline. Under a number of assumptions about the response of misfueling to price differential and shortage the overall environment impact due to the policy could be environmentally harmful. Not much is gained by reswitching of an already poisoned catalytic converter while it is a clear loss to environmental air quality if any new misfueling occurs. In a different context, a condition of no shortage, compressing the price differential could be a useful policy.

Other options analyzed, along with a very brief statement of conclusions, are:

Short-Term Options

- Allowing the use of MMT for the summer of 1979: To the extent that the production of unleaded gasoline can be increased using the additive MMT, failure to enforce the ban on it would be environmentally helpful on balance during a period of shortage.
- Increased use of lead in leaded gasoline: In a period of shortage this policy would aid in the production of leaded and unleaded gasoline and marginally reduce misfueling.

Intermediate-Term Options

- Introduction of three-way catalytic converter: The three-way catalytic converter is said to be more sensitive to poisoning than the device currently in use. Introduction of the sensitive converter in a period of shortage of unleaded gasoline could worsen the air quality problem. Policy on timing of the introduction of the three-way converter should be reviewed.
- Tax-subsidy schemes to reduce price differential: Compression of the price differential between unleaded and leaded gasoline involves income transfer. The desirability of these transfers is a value judgment that must be faced. In a period of no shortage such a policy would reduce the incentive to misfuel. In a period of shortage of unleaded gasoline as noted earlier the same policy most likely would be counterproductive as a means to protect the environment.
- Mandatory closing of self-service stations: Because most misfueling is assumed to occur at self-service stations, closing them would reduce misfueling. However, forced closings of these stations would adversely affect the wellbeing of consumers. Whether the environmental gains to be made from reducing misfueling through this means more than compensate the loss in consumer well-being that would result from closing down self-service stations is a value judgment to be made.
- Federal law against misfueling: A federal law against misfueling would have to be actively enforced to be effective. Enforcement costs do not appear to be out of line with costs of enforcing other regulations. A crude estimate of enforcement costs is $30 million per year.

- Public information program: A public information program is not likely to be effective as a means to limit misfueling.
- Inspection-Maintenance programs: These programs, now being planned and implemented throughout the U.S., have promise as anti-pollution measures. To achieve maximum anti-pollution effectiveness, an IM program must require than an offender replace his catalytic converter. Some programs fine the offender about $75 but do not require replacement of the poisoned converter.
- Gasoline rationing: From the standpoint of environmental protection, gasoline rationing would be an effective measure. It would eliminate potential queueing, a major inducement to misfuel, and ensure a condition under which other anti-misfueling policies might be effective.
- Blending materials to increase supply of unleaded gasoline: Most of the blending materials that could be used to stretch the output of unleaded gasoline are not available in large amounts, thereby limiting their contribution toward easing the potential tightness in the unleaded gasoline market over the next few years.

Chapter I

INTRODUCTION

This study deals with short- and intermediate-term options to limit the use of leaded gasoline in automobiles equipped with catalytic converters. The misuse of leaded gasoline in cars designed to operate on unleaded gasoline is called "misfueling" or "fuel switching." A short-term option is a policy that could be implemented and take effect in the summer of 1979;[1] "intermediate-term" refers to the period 1980-1981.

Three short-term options are analyzed in this study. They are:

(1) Mandated price differential between unleaded and leaded gasoline

(2) Temporary suspension of ban on methylcyclopentadienyl manganese tricarbonyl (MMT) in unleaded gasoline

(3) Increased use of lead in leaded gasoline.

The following eight intermediate-term options are discussed:

(1) Delayed introduction of three-way catalytic converters

(2) Tax subsidy schemes

(3) Mandatory closing of self-service stations

(4) Federal law against misfueling

(5) Public information programs

(6) Inspection-maintenance programs

(7) Gasoline rationing

(8) Blending materials to increase supply of unleaded gasoline.

---

[1]Our ideas on short-term options were formulated in April and May, 1979 and were submitted to the Environmental Protection Agency in June, 1979.

A. THE REASONS FOR MISFUELING

The three generally accepted reasons for misfueling are:

(1) Price differential between leaded and unleaded gasoline

(2) Perceived superior engine performance of leaded gasoline

(3) Unavailability (shortage) of unleaded gasoline.

The Sobotka study[1] and the Department of Energy's Environmental Impact Statement (EIS)[2] emphasized price differential. It has been assumed (and observed to some extent) that as the price differential between unleaded and leaded gasoline widens, more and more motorists switch from the former to the latter. Recently (May 10-11, 1979), hearings by DoE addressed the policy option of a mandated price differential. Also numerous articles in the popular press have alluded to this cause of fuel switching.

Refiners of gasoline, particularly the large oil companies, have stressed the perceived performance cause. They claim that performance with regular unleaded gasoline is actually not much worse, but that commonly observed problems related to starting and "dieseling" are sufficient irritants to induce motorists to switch to leaded gasoline.

Until the summer of 1979, there had been very little public discussion on the third cause--unavailability of unleaded gasoline. This, in our opinion, can be an important reason for misfueling.

B. THE FRAMEWORK OF THE ANALYSIS

Our analysis of the environmental problem is conducted within the following guidelines:

---

[1]"An Analysis of the Factors Leading to the Use of Leaded Gasoline in Automobiles Requiring Unleaded Gasoline," Sobotka and Co., Inc. and Market Facts Incorporated, September 29, 1978.

[2]U.S. Department of Energy, *Environmental Impact Statement: Motor Gasoline Deregulation and the Gasoline Tilt*, January 1979.

(1) Misfueling poses a serious threat to the investment in catalytic converters. Measures to "solve" the problem which imply a serious relaxation of environmental standards (as opposed to delays) may be considered but are to be severely discounted.

(2) Policies to deal with short-run problems should be considered only if it can be demonstrated (reasonably argued) that they do not exacerbate intermediate- or long-term problems.

(3) To warrant serious consideration, a policy option must meet the test of feasibility. Feasibility encompasses technological, economic, and political constraints. It also implies timeliness.

(4) Each policy must be compared with an alternative. In a quantitative sense, at least, this means that policy review must be subject to a benefit-cost calculus. Hypothetically, a benefit-cost ratio of 2:1 should not be the basis of a recommendation if another policy yielding a ratio of 3:1 is available.[1]

Some examples of how these guidelines have affected our study can be given. Most of the oil company executives testifying at the recent rulemaking hearings (mentioned above) stated that inspection-maintenance (IM) programs would be the most effective way to limit misfueling. It was not considered as a short-term option because it lacks timeliness--IM programs cannot be established in time to have much impact on the situation as it is likely to exist in the latter half of 1979. Also, it is not within the power of the EPA or the federal government generally to put IM programs into effect. The use of a number of blending fuels such as alcohol and methyl tertiary butyl ether (MTBE) also would not meet the above guidelines of timeliness. These options are candidates for analysis as intermediate-term programs.

C. CLASSES OF OPTIONS

Most options to limit misfueling can be classified as demand- or supply-oriented. Some fit under both. Laws,

---

[1]We do not actually calculate quantitative benefit-cost ratios but the benefit-cost approach has influenced our analysis.

regulations, education programs, rationing, and excise tax-subsidy schemes work primarily on desire of motorists to purchase gasoline. Basically they are demand-oriented schemes. The use of additives, blending materials and investment tax credits are primarily supply-oriented. Deregulation and the recent rule allowing refiners to allocate a greater proportion of costs to gasoline production ("tilt rule") operate on both supply and demand.

Many of the demand-oriented proposals are suitable only for intermediate and long-run relief. While consumers probably would respond quickly to some of these initiatives, the programs are not suitable for the short-run because the period of implementation is from one to three years.

Options to promote refinery capacity through tax incentives usually will be effective with significant delays. For example, it takes about two years to install new reforming capacity and considerably longer--maybe four to six years--to commence production in a new refinery.[1] Therefore, some obvious options were not considered because of their lack of timeliness.

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[1]Robert L. Sansom and Dan Villette, "Refinery Permit Delays Evaluated," *The Oil and Gas Journal*, April 1979, pp. 78-83.

Chapter II

THREE SHORT-TERM OPTIONS

The central premise of our analysis of short-term options to limit misfueling is that a moderate shortage (three to eight percent) of unleaded gasoline in the summer of 1979 will be the major cause of misfueling.[1] Even a shortage of only three percent eventually would lead to the destruction of many catalysts, an immediate lowering of environmental quality, and a setback in long-term environmental goals. Most previous discussions on misfueling have focused attention on demand, a focus that was appropriate in a period of ample supply of unleaded gasoline and in a situation when price differential was assumed to be the major cause of misfueling. In this chapter we emphasize short-term supply policy options in contrast to demand-limiting options. To augment supply of unleaded gasoline for the peak driving months there are at least three feasible supply-augmenting approaches: (1) import more oil, (2) require refineries to increase unleaded gasoline at the expense of leaded gasoline, and (3) permit the use of certain octane-boosting additives. A fourth option, to increase gasoline production at the expense of heavier fuels, is contrary to previously stated national goals. The supply-oriented options discussed in this chapter pertain to the use of MMT--a manganese additive banned by the EPA since late 1978--and the further use of lead. A demand-oriented option discussed relates to a mandated price differential between leaded and unleaded gasoline.

---

[1]This statement was made before the actual shortage developed. The shortage was predicted by the Department of Energy as early as February 1979.

A. MANDATED PRICE DIFFERENTIAL

At the DOE hearing on a mandated price differential (May 10-11, 1979), three groups were represented: the oil industry, consumer-environmental organizations, and two federal government regulatory agencies (anti-trust division of the Justice Department and the FTC). The oil industry and the two government agencies opposed a mandated price differential on the grounds that it was anti-competitive and would constitute a disincentive to increasing supply of unleaded gasoline. The consumer-environmental groups favored a mandated price differential but thought that five cents was too high and that two cents would be better. Some of the difference in opinion can be explained by the fact that the opposing sides had differing views on whether price differential was a major cause of misfueling. As stated earlier, the oil company representatives were of the almost unanimous opinion that performance is the major reason for misfueling. In particular, some cars are harder to start, they "knock" and "diesel" (continue to run after the ignition is turned off) when using lead-free gasoline. These irritants, according to oil company executives, push drivers to misfuel more so than price differential. We accept both as causes for misfueling. At the same time, in our judgment, most attention should be focused on the third cause of misfueling--shortage of unleaded gasoline. In a period of actual or potential shortage, policy planning to limit misfueling should pay close attention to the effects of a shortage on misfueling. However, because of the importance many place on price differential, it is useful to consider the mandated price differential approach to limiting misfueling.

The following propositions underlie our analysis of the effectiveness of a mandated price differential:

(1) A widening price differential will cause fuel switching to leaded gasoline. In a period of shortage of unleaded gasoline, this undesired fuel switching

will help to alleviate the shortage, but the immediate relief comes at the expense of future environmental degradation.

(2) A narrowing in the price differential will encourage potential switchers not to misfuel and will encourage old switchers to reswitch; these effects will tend to increase the shortage of unleaded gasoline.

(3) Some fuel switching will occur due to a shortage of unleaded gasoline.

(4) The overall misfueling rate will depend upon two tendencies or elasticities: the tendency to misfuel due to price differential and the tendency to misfuel due to shortage.

(5) If protection of the catalyst investment is the policy goal, no beneficial purpose is served by reswitching an automobile with an already poisoned converter.

If the present price differential of approximately five cents were lowered, some economy-minded motorists who previously had switched to leaded gasoline would reswitch to unleaded gasoline. If their converters had already been poisoned, this action would not reduce hydrocarbon emissions. If the differential were lowered to close to zero, some motorists properly using leaded gasoline would, on occasion, use unleaded gasoline if there were a temporary outage of leaded gasoline. Both activities would create extra demand for unleaded gasoline. In a tight market situation for unleaded gasoline, both activities would contribute to lengthening the queue for it, causing consumer frustration, and, eventually, some switching to leaded gasoline by some motorists who are motivated out of frustration rather than economy.[1] The extent of this new switching would depend upon the shortage-induced switching tendency. As a practical matter, for a prolonged shortage of unleaded gasoline, this tendency or desire would approach 100 percent. This means that with cumulative frustration over a prolonged period, everyone is a potential switcher.

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[1] In this paper we do not develop a complete and integrated model of fuel switching; one is needed.

Obviously, not everyone could switch to leaded gasoline. If everyone attempted to switch there would be a huge shortage of leaded gasoline and a huge surplus of unleaded gasoline and, eventually, refiners would change their production runs. The most reasonable scenario is that there would be a large number of motorists willing to take either leaded or unleaded gasoline whichever one were more available. This indifferent use of gasoline would lead to the destruction of many catalysts, a worsening of air quality, and probably would slow down the rate of increase in unleaded gasoline production as the demand for leaded gasoline increased.

To place some bounds on the consequences of this process we made the following assumptions:

(1) The misfueling response to price differential is given as $M = a + D^{\beta}$ where M is the misfueling rate, a is the rate of misfueling at zero price differential (due to performance), D is the price differential in cents per gallon, and β is the "elasticity of response."[1] We assume that a = six percent, and β has a lower bound of 1.2 and an upper bound of 1.8. The lower and upper bound curves are plotted in Figure 1 and are roughly consistent with data in the EIS[2] and Sobotka report.[3]

(2) As the result of fuel switching, one-half of the converters subject to misfueling will be totally destroyed. This assumption has not been empirically tested.

(3) When a shortage of unleaded gasoline occurs for more than a few weeks, the switching rate due to shortage will be 60 percent of the shortage. This, also, is an untested assumption. It means, for example, that three percent of unleaded gasoline consumers will switch to leaded gasoline if there is a "prolonged" shortage of unleaded gasoline of five percent.*

(4) The current price differential is five cents per gallon.

(5) There are 40,000,000 cars with catalytic converters.

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[1] Independently, we assume that this function applies equally well for price rises and price declines. This is a controversial assumption as some reviewers have pointed out. See Note 1 at the end of the report.

[2] *Op. cit.*, Appendix B.

[3] *Op. cit.*, p. 24.

*This assumes that leaded gasoline will be available to permit a switch of that order.

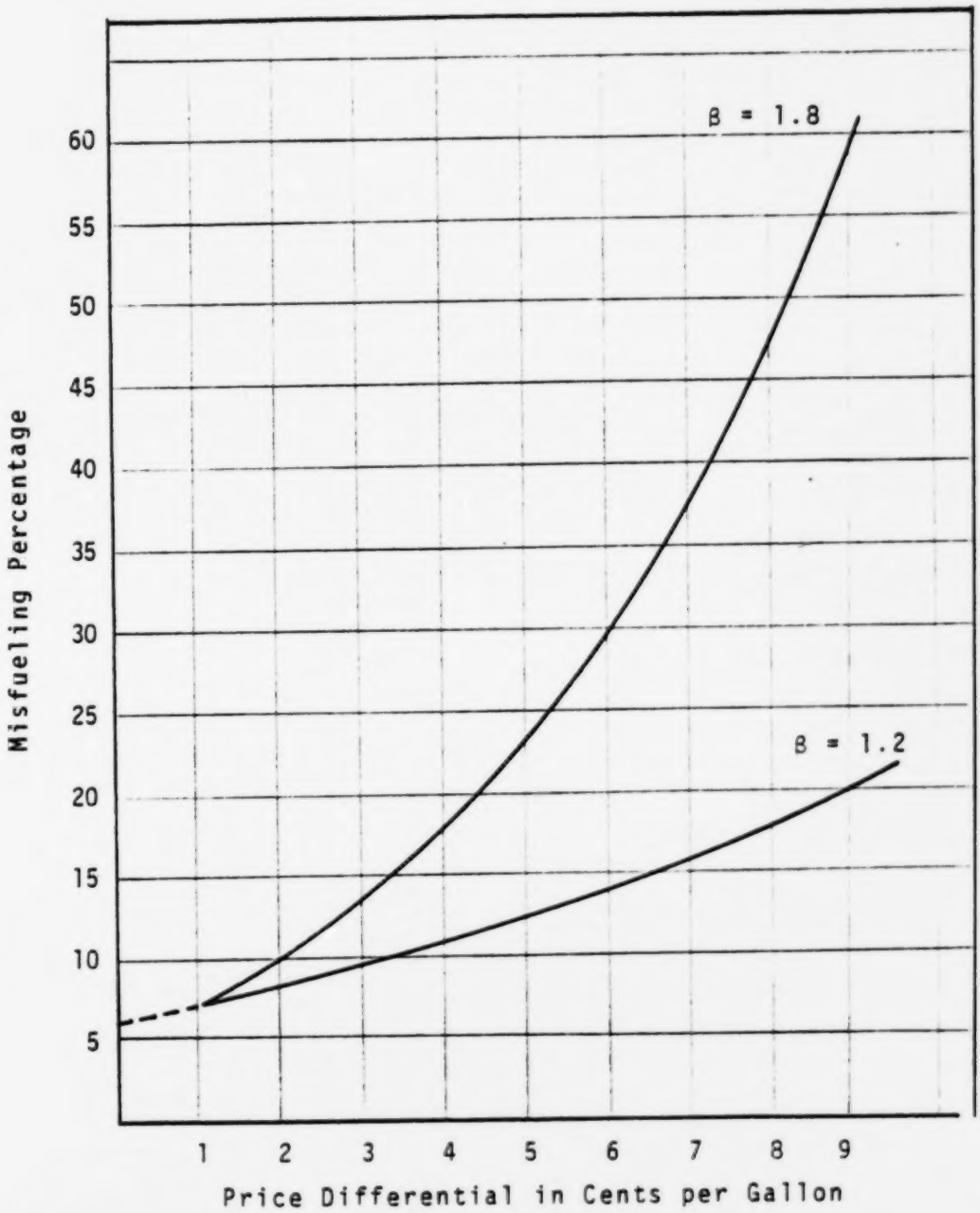

Figure 1. PRICE DIFFERENTIAL MISFUELING FUNCTIONS

At a price differential of five cents per gallon, the misfueling rate by our assumptions would be 12.9 percent on the lower curve and 24.1 percent on the higher curve. By assumption (2) half the catalysts subject to misfueling would be destroyed, i.e., 6.5 percent and 12 percent, respectively, of 40,000,000. Total destroyed catalysts would be 2,580,000 to 4,800,000. If the price differential were raised to nine cents per gallon, assuming the lower curve ($\beta = 1.2$), total catalyst destruction would be 20 percent (new misfueling rate) x .5 (assumption 2) x 40,000,000 = 4,000,000. *Additional* catalysts destroyed due to an increase in the price differential of four cents per gallon would be 1,420,000. How would a fall in the price differential effect the calculation of catalysts destroyed? Assume $\beta = 1.2$ (lower curve) and a fall in the price differential to one cent per gallon. According to the lower curve, the new misfueling rate due to price differential would be seven percent, a drop of 5.9 percentage points (from the misfueling rate at a five cent price differential). About 1,200,000 motorists would reswitch to unleaded gasoline, but this would not save any catalysts because reswitching, by our assumptions, will not restore a catalyst that has been destroyed.[1] However, it would create a shortage of unleaded gasoline of 5.9 percent, assuming that supply and demand in the unleaded gasoline market were in exact balance before the reswitching. This would lead to a misfueling rate (due to shortage) of 0.6 (assumption 3) x 5.9 percent = 3.54 percent and additional catalyst destruction of 0.0354 x 0.5 (assumption 2) x (40,000,000 - 2,600,000) (operative catalysts) = 662,000 due to the induced shortage. Raising or lowering the price differential would be harmful under the assumptions made. Calculations for other assumed values of β and price differentials are given in Table 1.

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[1]Actually, some regeneration of catalysts will occur. See P. Cutchis and R. Oliver, "Misfueling Estimates and Air Quality Effects," in P. Cutchis et al., *Papers Related to Gasoline Supply, Misfueling, and Environmental Air Quality for the Summer of 1979*, IDA P-1445, Arlington, VA: Institute for Defense Analyses, November 1979.

Table 1. ADDITIONAL CATALYSTS DESTROYED DUE TO CHANGES IN PRICE DIFFERENTIAL AND INDUCED SHORTAGE

Price Differential Response Factor = 1.2						Price Differential Response Factor = 1.8				
Differential	Additional Misfueling Rate	Additional Catalysts Destroyed[a]	Additional Induced Shortage[b]	Additional Catalysts Destroyed Lower[c]	Additional Catalysts Destroyed Upper[d]	Additional Misfueling Rate	Additional Catalysts Destroyed[a]	Additional Induced Shortage[d]	Additional Catalysts Destroyed Lower[c]	Additional Catalysts Destroyed Upper[d]
Cents	%	000	%	000	000	%	000	%	000	000
9	7.1	1,420	-	0	0	34.1	6,820	-	0	0
7	3.4	680	-	0	0	15.1	3,020	-	0	0
5	0	0	0	0	0	0	0	0	0	0
3	-3.2	0	3.2	359	599	-10.9	0	10.9	1,150	1,917
1	-5.9	0	5.9	662	1,104	-17.1	0	17.1	1,805	3,008

Assumptions:

[a]Fifty percent catalyst destruction as a result of misfueling.

[b]Reswitching induces unleaded gasoline shortage equal to reswitching rate.

[c]Misfueling rate due to shortage is 60 percent of the induced shortage percent and 50 percent catalyst destruction as a result of misfueling.

[d]Misfueling rate due to shortage is equal to the induced shortage percent and 50 percent catalyst destruction as a result of misfueling.

The major objection to mandating a price differential is that any differential set by regulation to relieve a short-term problem might become a contributor to worsening a long-run problem. In the long-run the price differential must reflect the costs of producing leaded and unleaded gasoline. Regulating this differential is contrary to the incentive system that motivates business decisions to increase output. Once regulations have been put in place, they are difficult to recall. The reason is that different pressure groups develop interests in regulations which are threatened upon removal. Thus, the process of imposing and removing regulations cannot be totally rational. As a result, large numbers of non-organized persons usually have to pay the price demanded by small numbers of organized persons. Economic analysis, even if it is correct, can be of little assistance in the short-run in a charged political setting. The main impression that one gains from studying the simulations in Table 1 is that if a price differential must be set, the current differential will be least harmful. To minimize the longer-term economic harm that might follow from the short-run policy of a mandated price differential, the regulation could have a "sunset" clause. It would lapse automatically after a stated period of time. This provision would be a signal to oil company decision-makers that investment initiated now will be justifiable in one to two years when it begins to contribute to increased production of unleaded gasoline.

A mandated retail price differential probably would reduce economic welfare if the mandated price differential became the actual differential.[1] In those cases where the mandated maximum now is exceeded, compliance could be obtained by reducing

[1]The mandated maximum would not necessarily become the actual differential in all or most cases because DoE pricing regulations at the retail and refining levels might prevent that from occurring. It would become the actual differential if the mandated maximum differential were set at a level below the constrained market differential.

the price of unleaded gasoline, raising the price of leaded gasoline, or a combination of both. In cases where the differential now is lower than that mandated, the most likely course would be to raise the price of unleaded gasoline.[1] There is also a question of how to undertake adjusting the price differential in order to be consistent with current price-setting regulations. For example, if the price differential now is legally above the mandated standard, adjustment to the differential might require violating the pricing regulations of one kind of gasoline. In any event, any action that causes the maximum allowable differential to become the actual differential is likely to cause a lowering in net consumer welfare, and to be measured by economists as consumers' surplus. Suppose a seven cents differential were reduced to five cents by raising the price of leaded gasoline by a penny and lowering the price of unleaded by a penny; in that event, about sixty percent of the gallons sold will fall by one penny. Ignoring the very minor quantity changes that would take place and assuming comparable price elasticities for both leaded and unleaded gasoline, this method of achieving the five cents differential over a period of a year would cause a loss in consumer welfare of about $200 million.[2] That is, the consumer losers to the regulation would lose this amount more than the consumer gainers would gain.[3] This cost estimate is only illustrative but it indicates that the welfare costs of adjustment probably are not negligible.

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[1]Prices of both will be rising this summer (1979). Therefore, these statements must be interpreted in relation to some moving price base rather than current prices.

[2]This calculation is based on the assumption that the split between leaded and unleaded gasoline is 60-40 of 100 billion gallons of gasoline consumed annually.

[3]Producers would gain the $200 if it were not taxed away.

B. REMOVAL OF BAN ON MMT

On May 30, 1979 the EPA temporarily suspended enforcing its ban on MMT as an octane booster for unleaded gasoline. MMT was banned under the Clean Air Act but continued in use until September 1978. Prior to this time the EPA invited interested parties to make an environmental case for its use. The briefs were inconclusive because the proponents of MMT, particularly the Ethyl Corporation, were not able to demonstrate to EPA's satisfaction that the additive did not harm the environment.[1] During the period of its use, the amount of MMT applied was about 1/16 gram Mn per gallon of gasoline. Some tests (by General Motors) using 1/8 gram Mn per gallon indicated that cars designed for 1980 would not be able to meet the hydrocarbon emissions standards with MMT in gasoline and that the additive tended to "plug" the catalytic converters.

Early in May, Ethyl Corporation and a group of oil companies led by Tenneco, Inc. urged the EPA to suspend the ban on MMT. Their arguments included the following points:

(1) Evidence that MMT was harmful to the environment was never demonstrated.

(2) Even if it caused harm to the environment in concentrations of 1/16 gram Mn per gallon, in concentrations of 1/32 gram Mn per gallon it would not be harmful.

(3) By using 1/32 gram Mn per gallon, research octane could be boosted sufficiently to raise the production of unleaded gasoline by 340,000 b/d at constant octane.[2]

(4) In the small amounts suggested above no harm would be done to the catalyst. Ethyl Corporation has argued, in fact, that small amounts of MMT improve the performance of the catalyst.

Our analysis of the recent EPA decision starts with the proposition that environmental air quality will be reduced in the June-September period with or without the use of MMT as an

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[1] *Federal Register*, Vol. 43, No. 181, September 18, 1978.

[2] All of this gain would come at a sacrifice of leaded gasoline of the same amount. See comments on pp. 17-18 below. For more recent information on MMT usage see foreword to this study.

octane booster.[1] No choice that EPA could make at this time is a good choice on an absolute scale--the choice must be one to minimize harm.

In making this decision EPA faced a dilemma. The dilemma was this: Use of MMT would increase the octane pool and, as one option, refiners could increase output of unleaded gasoline for a given refinery throughput of oil. The added quantity of unleaded gasoline would reduce its shortfall over the summer months and, consequently, reduce whatever misfueling that would occur due to shortage. For automobiles that are misfueled, hydrocarbon emissions increase enormously. Without MMT, a larger fraction of cars would misfuel and air quality would deteriorate;[2] many catalysts would be poisoned permanently. On the other hand, if MMT were permitted, HC emissions would increase slightly in all cars in the unleaded fleet and air quality would deteriorate. In both cases, air quality deteriorates. The question is clear: Under which option would it deteriorate less?

To answer this question we need some facts about the potential increase in HC emissions due to MMT, increase in HC emissions due to misfueling, and the potential misfueling rate due to shortage of unleaded gasoline. The answer can be given in a straightforward way. Let MR(S) be the misfueling rate due to shortage, h_1 the added HC emissions in grams per mile due to misfueling, and h_2 the added HC emissions in grams per mile due to MMT. All other things equal, removal of the ban on MMT is desirable as long as

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[1]At the time EPA suspended the ban on MMT, the Department of Energy permitted oil companies to charge an additional two cents per gallon on additional production of unleaded gasoline. This rule would stimulate production of unleaded gasoline. We have made no effort to analyze or predict the effect of this regulation. We are concerned here only with the effect of suspending the ban on MMT.

[2]Our analysis of the MMT decision is centered on emissions of hydrocarbons. There may be potential dangers associated with the use of MMT but the data are so poor that we could not take into account other consequences.

$$MR(S) > h_2/h_1 \quad .^{1}$$

The ratio, h_2/h_1, is called the "critical ratio." The essence of the above formula is whether a slight increase in emissions in many cars is worse than a high increase in relatively few.

To place this problem in perspective we make the following assumptions:

(1) The misfueling rate due to shortage is proportional to the percent shortage. This is the high estimate assumed in Table 1.

(2) Added HC emissions due to misfueling are four grams per mile at the low end and six grams per mile at the high end.[2]

(3) Added HC emissions due to 1/32 gram Mn per gallon are in the range of 0.1 to 0.5 per mile.[3]

Given these assumptions, the "critical ratios" are .025 to .125 for h_1 = 4 grams per mile and .017 to .083 for h_1 = 6 grams per mile. Boundary loci are lines connecting all points where $MR(S) = h_2/h_1$. These are shown on Figure 2. Points to the left of the loci are coordinates of percent shortage and h_2 indicating that MMT usage will cause less air pollution than banning it. For example, if the expected shortage without MMT

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[1]See Appendix A.

[2]In DoE's Environmental Impact Statement, six grams per mile is the implied average. See pp. III-7, 8 of that report.

[3]According to Mr. H.E. Hesselberg, Vice President of the Ethyl Corporation, 0.1 gram per mile is the "worst case." A recent study by the Coordinating Research Council found that HC emissions due to MMT were about 1/10 gram per mile at 50,000 miles and more than that at 15,000 miles. (Reported in Martin Tolchin, "Questions Are Raised on MMT Effects," *New York Times*, Wednesday, June 6, 1979, p. D3.) A study by General Motors claimed that 1/8 gram MMT per gallon would increase HC emissions for 1980 cars by 85-100 percent. Since 1980 cars are to achieve an HC emission standard of 0.4 grams per mile, 85-100 percent implies a range of .74-1.16 grams per mile with 1/8 gram Mn per gallon. If added HC emissions are linear in the amount of MMT used, 1/32 gram Mn per gallon would add 0.09 to 0.19 grams per mile. This extrapolation on average increased the Ethyl "worst case" estimate by 50 percent. But even this extrapolated figure is at the low end of our assumed range.

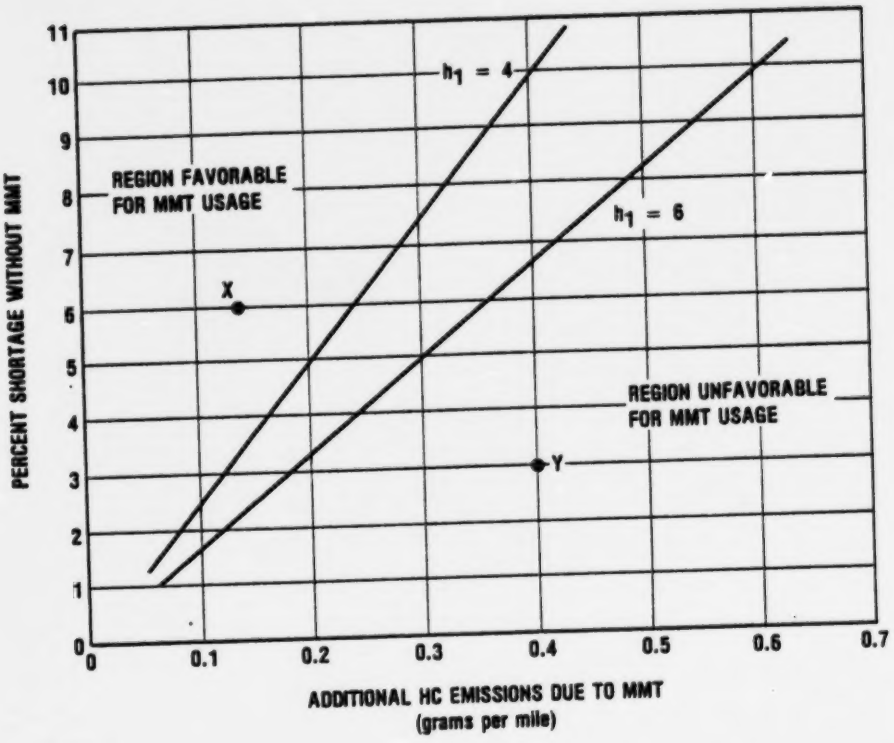

Figure 2. BOUNDARY LOCI FOR DETERMINING MMT USAGE

were six percent and MMT causes additional hydrocarbon emissions of 0.15 grams per mile (point X in Figure 2), MMT will cause less harm to the environment than the shortage which would occur if it were not used, regardless of whether h_1 = 4 or 6. Point Y, representing a low potential shortage and a relatively high h_2, is in the undesirable area.

The amount of increased unleaded gasoline production made feasible by allowing the use of MMT is crucial to the decision, for that number determines the extent to which a potential shortage can be relieved. 340,000 b/d increase in unleaded gasoline could remove a shortage of about 10 percent; but we doubt that the EPA action on MMT will actually result in an increase in unleaded gasoline by that amount. The reason is that refiners are not likely to sacrifice equal production in

leaded gasoline to produce additional quantities of unleaded gasoline. For more realism a different estimate is needed. Ethyl Corporation analysts have stated: "Various refiners have estimated that the inability to use MMT (at 1/16 gram Mn per gallon) will reduce *total* gasoline production by four percent to eight percent during the next several years."[1] Note that this statement applies to *total* gasoline and 1/16 gram Mn per gallon. An increase in total gasoline production by four to eight percent is 300 to 600 thousand barrels per day. If this were prorated by the current practice, 120 to 240 thousand gallons per day would go to unleaded gasoline. If 1/32 gram Mn has somewhat more than half the octane boosting capability as 1/16 gram, we should expect an increase in unleaded gasoline due to the MMT regulation above of about 70,000 to 140,000 b/d or three to four percent of current production. That order of increase would be marginally useful, but mainly for reasons of intermediate-term concerns.

The short-run advantage in using MMT probably is eclipsed by the intermediate-term advantage. If MMT were used over the summer months, it is possible that its use could save between 1.1 to 1.5 million catalysts. This estimate is based on the assumptions that (1) the expected shortage of unleaded gasoline could be reduced by three to four percent by using MMT, (2) the percent of motorists who would misfuel due to shortage is identical with the percent shortage, and (3) eventually the percent of catalytic converters destroyed is equal to the misfueling percentage. If over a million catalytic converters were destroyed due to a shortage that could be avoided by permitting shortage-induced catalytic poisoning would continue even after the shortage disappeared. Air pollution due to shortage would be a continuing problem, whereas the additional air pollution

[1]George H. Unzelman and George W. Michalski, "Octane Improvement Economics—Antiknocks and Alternatives," NPRA Paper AM-79-46 Presented at the 1979 National Petroleum Refiners Association Meeting, March 25-27, 1979, pp. 5-6.

due to MMT use would not be continuing, it would be restricted only to the period of the shortage.

Let us assume a four percent shortage if MMT were not used and zero shortage if it were used. Assume further that the added emission of HC is 0.2 grams per mile with MMT (h_2 value) and 6 grams per mile due to misfueling (h_1 value). Suppose that the fleet of catalytic converter cars is 40 million and that each car is to be driven 3,000 miles over the June-August quarter. Under these assumptions the following estimates were derived:

<u>For June-August Quarter</u>	
Increased HC emissions due to MMT	24,000 metric tons
Increased HC emissions (without MMT) due to four percent shortage	28,800 metric tons
<u>For Subsequent Quarter</u>	
MMT no longer used	?
Increased HC emissions due to five percent shortage in June-August quarter	28,800 metric tons

If MMT were used only to relieve a temporary shortage and then discontinued after the shortage threat abated, the added HC emissions due to MMT might be temporary.[1] If MMT were used on a permanent basis, the 24,000 tons added HC emissions per quarter would continue, but that is one-fifth less than the added HC emissions that would occur due to a shortage in the immediate quarter, even if the shortage subsided in future quarters.

There is a possibility that the oil companies will use MMT to boost octane levels in unleaded gasoline rather than increasing production of unleaded gasoline at current octane levels.[2]

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[1]Due to the built-up deposits during use, additional HC emissions would probably not fall to zero once MMT were discontinued. Whether 1/32 gram Mn causes any "plugging" is a controversial issue.

[2]We do not consider the probability to be high, particularly since the penny rule was relaxed at the same time that EPA stopped enforcing its ban on MMT.

This could be realized by increasing the ratio of premium to regular unleaded, by adding an intermediate grade, or by raising the octane level of regular unleaded gasoline. Such actions not only would negate the favorable potential from using MMT but would also exacerbate the problem. Drivers who have misfueled due to performance might reswitch to the higher octane unleaded gasoline, the shortage then would increase, more misfueling would occur, more catalysts would be destroyed, and air quality would drop even further. Also, the reswitchers' catalysts would not be restored.

To the extent that EPA and DoE can fix octane levels, including the proportions of premium and regular unleaded gasoline, we recommend that they disallow an upward octane creep in the short run.[1] It would affect the shortage-reducing potential of MMT use and would negate, in our opinion, the major reason for allowing its use.

The facts on MMT usage are confusing. The four month period of suspension of the ban could be most instructive. It could be a period of systematic observation and scientific evaluation of the results with respect to (1) added emissions, (2) effect on the efficiency of the catalytic converter, and (3) effect on output of unleaded gasoline. The last item will be confounded because of the two cent incentive. The data would be most useful in a decision on intermediate- and long-run environmental protection policies, and they should be collected.

C. INCREASED LEAD CONTENT IN GASOLINE

Currently, the average lead content is 2.0 grams per gallon in leaded regular gasoline and 2.25 grams in the premium grade.[2]

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[1] In the longer-run there probably should be an upward octane creep to discourage performance-related misfueling.

[2] George H. Unzelman and George W. Michalski, "Octane Improvement Economics--Antiknocks and Alternatives," NPRA Paper An-79-46, *op. cit.*, Table A-1, p. 21.

The lead pool average in all gasoline is approximately 1.3 grams per gallon. Under the lead phasedown regulation, the lead pool average was to drop to 0.5 by October 1979. The phasedown schedule has been amended and a lead pool average of 0.8 grams per gallon will be put into effect in October 1979.[1] At present there are no effective restrictions on lead use. It is significant to note for our analysis that up to 85 percent of production was not subject to lead restrictions in the first five months of 1979.

As one option to the near-term environmental problem, it is useful to consider the consequence of encouraging an increase in the lead content in leaded gasoline over the next few months. One way to "encourage" use would be to suspend the ban on lead use for approximately 15 percent of production. (This, in fact, took place on May 25, 1979.)

Regarding air pollution in the short-run, the case for increased lead is a little more complicated than for MMT. It will marginally increase lead pollution but could reduce emissions of HC to the extent that increased concentrations of lead in gasoline would boost gasoline production and alleviate the shortage. In the case of MMT, the tradeoff is HC for HC; in the case of lead, it is lead for HC. Using more lead in leaded gasoline could be helpful in reducing shortages in both leaded and unleaded gasoline. If it contributes to eliminating the shortage in leaded gasoline, the likelihood of a motorist with no converter using unleaded gasoline is decreased; this, in turn, removes a potential demand for unleaded gasoline. This effect could be significant if a major shortage in leaded gasoline were to develop; but we shall ignore it here.[2]

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[1]This regulation will not apply to all refiners.

[2]Use of increased lead in leaded gasoline would presumably lead to more rapid poisoning of catalysts if misfueling does take place, but we have no data on this effect.

It has been estimated by the Ethyl Corporation that full use of lead in all gasoline could save up to 500,000 b/d of crude oil.[1] This impressive figure is not relevant for our analysis of short-run solutions. It is based on the added gasoline that could be produced in 1990 if all gasoline were to be leaded rather than most of it being unleaded. It presupposes a different emissions control technology for the catalytic converter. Also, statements about "saving gasoline" by various means are irrelevant to our analysis. "Saving gasoline" usually means that if something else were to happen instead of that programmed, gasoline production would decline less than expected under the program to be replaced. Saving gasoline in that context is not a useful concept for short-run analysis. Rather, the question is: What can be done to *increase* production in the short-run?

The same study quoted above estimates "potential 1980 crude savings" by increasing the concentration of lead in premium and regular leaded gasoline. By raising lead content in premium from 2.25 to 3.00 grams per gallon and in regular from 2.00 to 2.50 grams per gallon, the change in savings of crude is estimated to be 62,000 b/d.[2] A linear extrapolation undoubtedly will overstate the crude savings. Nevertheless, an extrapolation to 3.75 grams per gallon in premium and 3.00 grams per gallon in regular will push the lead pool average to 2.00 grams per gallon and will add, at most, an additional 62,000 b/d to the saving of crude. Thus, it might be possible to free 124,000 b/d crude by increasing the lead pool average from 1.30 to 2.00 grams of lead per gallon. The freed-up crude could then be processed as all other crude to yield an increase in gasoline

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[1] G.W. Michalski and G.H. Unzelman, *Effective Use of Antiknocks During the 1980s*, Preprint No. 26-79, American Petroleum Institute, May 1979.

[2] *Idem.*, Table 7, p. 23.

production of 0.8 percent or 62,000 b/d.[1] However, the refinery runs under the new lead regime would likely change the mix of products and might yield twice the calculated increase in gasoline production to 124,000 b/d, of which 45,000 b/d would be unleaded. Thus, measured as potential increase in gasoline production, raising the lead content by 0.7 grams per gallon (lead pool) would have a similar impact as allowing the use of MMT.

The question is how to "encourage" added lead use temporarily. If up to 85 percent of production is already exempt from lead content, we would assume that those refiners are already using the optimal amounts of lead. Undoubtedly, their linear programs have figured out the most profitable concentration. If this is true, only about 15 percent of the gasoline production would be affected and, presumably, increased production potential would be much less than the figure estimated above. Admittedly, our estimate of the extra gasoline (and a pro-rata share to unleaded) that could be produced in the short-run by raising the lead pool average is very rough. Its importance lies in the fact that the figure is relatively small rather than large. Thus, as a short-run measure, increasing the lead content in leaded gasoline does not appear to be a major prospect, although it will be useful.[2]

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[1]Calculations based on the following estimates: crude runs, 15,000,000 b/d; gasoline output 7,500,000 b/d; percent unleaded gasoline, 36.

[2]This opinion certainly does not bear on the long-run question about the economic and social desirability of replacing catalyst technology with lead tolerant engines and lead traps to remove the lead.

Chapter III

INTERMEDIATE-TERM OPTIONS

A. ASSUMPTION OF INTERMEDIATE-TERM SHORTAGE

Intermediate-term options are those which could be brought to bear upon the problem of misfueling during the period 1980-1981. The short-run options treated in the previous chapter could be extended into the next two years; but analyses of these policies extended as intermediate-term solutions would not necessarily be the same as those presented under short-term options, because conclusions are dependent on the assumptions (scenarios) chosen. An assumption of the preceding analyses was that the major cause for misfueling in the summer months would be a shortage of unleaded gasoline. If the shortage were to disappear in the intermediate-term, the analyses likely would yield different results. For example, if there were no shortage, the advantages from using MMT would lie in cost or reduction in crude oil imports.

In our discussion of intermediate-term options we shall still be concerned with potential shortages of unleaded gasoline. Whatever shortages do occur are likely to be regional in scope and, perhaps, not prolonged. Our chosen scenario is one of intermittent periods of shortages due to unpredictable shocks to the production-distribution system rather than to fundamental problems of supply and demand. This scenario is based upon our reading of the limited available information which we summarize in Appendix B.

There is a second reason for assuming intermittent shortages of unleaded gasoline in our analysis of intermediate-term options: with this assumption, some counterintuitive results emerge. Counterintuitive results are not necessarily desirable for policy purposes because they can also be counterproductive if their derivations are based on incorrect assumptions; yet, rational policies cannot be made without considering all important probable outcomes. Some reviewers of this study have expressed the opinion that we overstress the motive leading to misfueling due to shortage at the expense of the price differential motive. If we overstress shortage it is only because much more is already known about the effects of price differential and our analysis is intended to supply some less known results to balance the total spectrum of information. We do not make predictions; we only point out logical consequences of environmental policies in the event of shortages.

Our concern with possible shortages has influenced our discussions on the following options: delayed introduction of the three-way catalyst, tax-subsidy schemes, gasoline rationing, and blending materials to increase supply of unleaded gasoline. Shortage of unleaded gasoline is not a necessary assumption in our discussions on closing down self-service stations, federal law (rule) against misfueling, and inspection-maintenance programs.

B. DELAYED INTRODUCTION OF THREE-WAY CATALYST

Potential catalyst destruction is highly sensitive to the severity and length of shortages. This statement is based on some calculations made with the use of a cumulative binomial probability distribution which is reproduced in Table 2.[1]

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[1]See P. Cutchis and R. Oliver, "Misfueling Estimates and Air Quality Effects" in P. Cutchis, *et. al.*, *Papers Related to Gasoline Supply, Misfueling, and Environmental Air Quality for the Summer of 1979*, IDA P-1445, November 1979. The cumulative binomial probability distribution is (continued on next page)

Table 2. FRACTION OF CATALYSTS DESTROYED BASED ON MODEL USING CUMULATIVE BINOMIAL DISTRIBUTION

Shortage Percent	Misfuelings Needed to Destroy Catalyst	Fraction of Catalysts Destroyed After		
		10 Fuelings	30 Fuelings	100 Fuelings
1	1	.0956	.2603	.6340
	3	.0001	.0033	.0794
	8	.0000	.0000	.0000
5	1	.4013	.7854	.9941
	3	.0115	.1878	.8817
	8	.0000	.0000	.1280
10	1	.6513	.9576	1.0000
	3	.0702	.5887	.9981
	8	.0000	.0000	.7940

Suppose that (1) a motorist with a catalytic converter-equipped car misfuels whenever he is unable to obtain unleaded gasoline on any fueling attempt,[1] (2) there is a five percent shortage of unleaded gasoline,[2] (3) three misfuelings are required to destroy the catalyst and there is no catalyst regeneration, and (4) the period of shortage is long enough (about five weeks) for 10 fuelings. Under these assumptions, about one percent of all catalysts would be destroyed. For a ten percent shortage, with everything else the same, seven percent of

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(cont'd)

$$f = \sum_{i=m}^{m} \binom{n}{i} x^{i} (1-x)^{m-1}$$

where f is the fraction of catalysts destroyed, x is the percent shortage, n the number of fuelings during the shortage, and m the number of misfuelings required to destroy a catalyst.

[1]This implies that leaded gasoline will be available.

[2]A five percent shortage means that unleaded gasoline will not be available to the average motorist one time in twenty fuelings.

the catalysts would be destroyed. Given a five percent shortage lasting for about a year, at two fuelings per week, 88 percent of the catalysts would be destroyed, if three misfuelings are required to poison the catalyst. While these computations exaggerate the potential problem, they are illustrative of an important point: In a period of shortage a "robust" catalytic converter with perhaps slightly less efficiency than a "sensitive" converter with greater anti-pollution efficiency will probably be the superior instrument for protecting the environment.

An example of a "sensitive" converter may be the three-way converter which, presumably, will be fixed on 1981 model cars. In a period of abundant supplies of unleaded gasoline, the three-way converter may have much to recommend it. But if a three-way converter can be poisoned after one misfueling, introducing it in a period of shortage could be harmful; as Table 2 indicates, given a five percent shortage and ten fuelings, the fraction of catalysts destroyed rises by a factor of 34 in comparison to the present catalyst if we assume that three misfuelings are required to destroy it. Sensitive converters which have great anti-pollution potential will be effective only in a situation of abundant supply of unleaded gasoline.

Accordingly, one may argue that next year is too early to introduce the three-way converter. While this suggestion in no way can be considered as an "option to limit misfueling," it can be considered as an option to prevent environmental degradation. The suggestion is valid only if one expects a shortage to occur next year or shortly thereafter and if the three-way converter is prone to poisoning after fewer misfuelings than present converters.

C. TAX-SUBSIDY SCHEMES

Tax-subsidy schemes for bringing about desired outcomes have long been favored by many economists. These schemes are easy to employ and if placed in the proper manner do not affect

marginal relationships; for that reason, they are relatively efficient. Two well-known economists writing on the misfueling problem have suggested:[1]

> A long-term solution, involving less regulation, would require Congressional passage of a "balancing tax" that equalizes the price of leaded and unleaded fuel by putting a tax on one that acts as a subsidy on the other. Such a tax ought to become a major goal for environmentalists and everyone else interested in a cleaner environment and less regulation.

The validity of the above statement depends critically upon the scenario. The condition under which many economists would accept the tax-subsidy prescription is that supply and demand are in approximate equilibrium. *Our analysis begins with the assumption that there will be excess demand for gasoline over the intermediate term.* Our formal analysis yields the following conclusions:[2]

(1) In a period of shortage of unleaded gasoline any tax on leaded gasoline, subsidy to unleaded gasoline, or combination of both will help to generate a greater shortage of unleaded gasoline. If some people misfuel due to frustrations of shortage, additional catalysts will be destroyed. On the other hand, lowering the price differential between leaded and unleaded gasoline by tax-subsidy schemes will not restore already destroyed catalysts of those misfuelers who reswitch to unleaded gasoline. The analysis is consistent with that previously presented under the short-run option of a mandated price differential. The conclusion is that tax-subsidy schemes are most likely to harm the environment rather than improve it. If no shortage is anticipated, tax-subsidy schemes could be useful in preventing additional misfueling.

(2) Tax-subsidy schemes have income redistribution effects which in some cases may be politically unacceptable.

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[1]Charles A. Lave and Lester B. Lave, "Curbing Lead Poisoning by Drivers," *The New York Times*, February 2, 1979, p. A25.

[2]See R. E. Kuenne, "Taxation and Subsidization Policies as Means of Reducing Misfueling in Times of Gasoline Shortage," in P. Cutchis, *op. cit.*

If the tax on leaded gasoline were raised, this would constitute an income transfer away from owners of lead-consuming automobiles and also away from producers of leaded gasoline to general revenues. There is the general philosophical question of why a certain group of old car owners should bear the burden of paying for environmental improvements. A more politically charged question would arise if we knew that a disproportionate number of older automobiles were owned by the poor.

A subsidy on unleaded gasoline would benefit consumers of that type of gasoline and probably the oil companies that produce it. Not accompanied by a balancing excise tax on leaded gasoline, this subsidy would be an implicit tax on the general taxpayer.

(3) In the long-run when, presumably, shortage cannot be a chronic problem, tax-subsidy schemes could prevent misfueling due to price differential and would not add to misfueling due to shortage. In this situation tax subsidy schemes would be an aid to environmental quality; but the costs implied in item (2) above would still have to be considered.

We have assumed a precarious balance of supply and demand over the next two years. This could be manifest in a small continuous shortage or periods of shortage followed by periods of balance. But even in national balance there are likely to be regional problems of allocation. The value of employing tax-subsidy schemes as means to limit misfueling depends upon the assumption about gasoline shortages. Such schemes could be beneficial in an environment of no shortage, but they could be counterproductive if shortages were to occur.

D. MANDATORY CLOSING OF SELF-SERVICE STATIONS

One approach to minimizing misfueling is to require the closing of all self-service stations. The validity of this approach must rest, in the last analysis, on whether the gain to the environment is greater than the cost to the consumer (loss in consumer welfare) that would accompany such an action. Self-service stations grew very rapidly in response to consumer demand for them and this way of marketing gasoline must reveal

net welfare benefits by the fact that they exist and compete with full-service stations in the context of free choice. To deny consumers the use of these stations clearly implies a loss to their wellbeing. An attempt is made here to calculate this cost.

Mandatory closing of self-service stations would be a rather drastic intervention in the market place and could not be justified unless total welfare were improved by the intervention. A major premise behind such a move to close self-service stations must be that they are the contact points for misfueling. At the least, one assumes that misfueling is difficult at full-service stations where it is illegal and subject to a fine of up to $10,000 for an attendant to participate. In any event, we assume that closing down self-service stations will eliminate most of the misfueling that takes place. A second assumption on which our analysis depends is that gasoline will be in short supply over the next two years.

With a shortage in gasoline, while its price is still subject to control, we would expect to see the price differential between full and self-service stations decline to the extent that pricing regulations allow it to happen. If the price differential were to fall to zero, the economically oriented consumer would gain no advantage in purchasing gasoline at self-service stations. The natural prediction from economic theory, that price differential would decline as competition declines due to a shortage, seems to be borne out by the data in Table 3. Both for leaded and unleaded gasoline, the price differential between the two types of service fell by about half between early March and late June 1979 just as gasoline allocations were falling.

Over the same period there was a significant reduction in the total number of self-service stations. They were closing on their own as the opportunities for raising prices developed. In March and April 1979 almost 4,000 split-island stations

Table 3. PRICE DIFFERENTIAL BETWEEN FULL AND SELF SERVICE STATIONS

	(Cents per Gallon)	
Lundberg Letter	Leaded Regular	Unleaded Regular
March 2, 1970	3.90	2.92
April 6, 1979	3.32	2.51
April 27, 1979	2.50	2.02
May 27, 1979	2.07	1.89
June 29, 1979	1.94	1.89

switched mode of operation; 3,100 went to full-service and 900 to self-service. Thus, as the number of full-service stations grew at the expense of split-island stations, so did the number of self-service only. According to the Lundberg letter,[1]

> ...self-service islands were being eliminated at many stations, presumably to do away with lower prices. Later these same retailers switched both islands to self-service, but maintained full-service prices.

Evidently, there was a tendency both to maintain the highest price and to eliminate service. Consumers clearly were injured by this tendency which was encouraged by the shortage and price controls.

To compute a measure of the transfer of benefits away from consumers and to producers, we require the data in Table 4. While there were more full-service stations than self-service stations, note that, by volume of sales, the self-service stations dominated. By volume of sales the division was 54 percent for self-service (only) stations and self-service (split-island), and 46 percent for full-service including full-service at split-island stations. Of the approximately 100 billion gallons sold annually, suppose that 40 billion are unleaded and 60 billion are leaded. Assume that 54 percent of both types of gasoline are

[1]Lundberg Letter, April 27, 1979, p. 2.

Table 4. PERCENT OUTLETS AND VOLUME OF SALES AT FULL-SERVICE, SPLIT-ISLAND, AND SELF-SERVICE STATIONS

	Full-Service Only	Split Island		Self-Service Only
		Full-Service	Self-Service	
Outlets				
Major Brands	38.3	51.0		10.8
Non-Major Brands	42.1	9.0		48.9
All	39.5	37.4		23.0
Volume				
Major Brands	25.0	29.0	27.0	19.0
Non-Major Brands	32.0	5.0	7.0	56.0
All	27.0	19.0	19.0	35.0

Source: Lundberg Letter, April 27, 1979.

sold as self-service. Then, at an annual rate, 32.4 billion gallons of leaded and 21.6 billion gallons of unleaded gasoline were sold in the summer of 1979 in the manner of self-service. Using the price differential data in Table 3, we calculate that the annual rate of transferrence from consumers to retailers was $635 million in leaded gasoline and $222 million in unleaded gasoline. The total is $857 million. If it is also true that regular service deteriorated, then these customers also lost; so the total loss was greater than our calculation.

Assuming the price differentials of June 29, 1979, the total maximum dollar benefits remaining to consumers was approximately $1.04 billion. The actual total would be less (and, maybe, consierably less) because, presumably, most self-service customers would cease to purchase at self-service stations before the price differential were completely eliminated. Thus, it appears that the mandatory closing of self-service stations in a prolonged

period of shortage would cost about one percent of the value consumers place on gasoline. This estimate assumes that most of the self-service stations closed would choose to operate at full-service so that locational convenience would not be sacrificed.

A compromise solution would be to close self-service for leaded gasoline while allowing unleaded customers to use this form of service. This compromise solution would reduce the loss in consumer benefits to about $630 million and would achieve the goal of minimizing misfueling; but as a policy it might seem very unfair to motorists who legitimately use leaded gasoline.

While it would appear that the mandatory closing of self-service stations is a drastic measure, in a period of prolonged shortage of gasoline, it is an option. However, the decision to close self-service stations should not be made unless the calculated benefits from environmental improvement were larger. This measure would be unjustified if there were cheaper ways of achieving the same results, such as a federal law against misfueling and inspection-maintenance programs.

E. FEDERAL LAW AGAINST MISFUELING[1]

The difficulty in maintaining programs to deal with environmental protection arises from the fact that a cleaner environment is a public good to be enjoyed by all, while producing the cleaner environment is nobody's legal responsibility. Since few really consider themselves privately responsible, it would be almost impossible to maintain air quality without a central authority imposing restrictions on all. Most agree that when it is nobody's business to provide goods that everyone wants, there is

[1]The analysis of this section applies also to state laws and any federal regulation that might directly punish misfuelers.

a valid claim for action by the central authority. Upholding the Clean Air Act requires federal regulations which fix culpability on businesses or individuals who violate the Act. On philosophical grounds one could make the same case for restricting air pollution due to misfueling by passing a federal law which would make it a crime to misfuel and would establish an appropriate penalty.

A federal law against misfueling would have to be justified on grounds of cost effectiveness. The benefits in terms of environmental quality from preventing misfueling can be calculated.[1] Our present concern is to outline a methodology for estimating the cost of enforcement of a federal law against misfueling. This cost must then be compared with the costs of alternative programs which would achieve the same results to determine whether it was "cost-effective."

First we make the very convenient (but, perhaps, artificial) assumption that each potential misfueler is a "rational economic man" who will break the law only if the expected economic (monetary) benefits from the act are greater than the expected costs. The economic benefits (B) are calculated as the number of gallons used (G) times the price differential (DIF) between leaded and unleaded gasoline. The expected costs (E(C)) are derived by multiplying the probability of apprehension (P_A) by the known economic penalty (PEN). Thus, the "rational" potential misfueler would recognize a critical point, or point of indifference, with respect to misfueling when

$$B = E(C)$$

and

$$G.DIF = P_A.PEN \ .$$

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[1] For example, see P. Cutchis and R. Oliver, "Misfueling Estimates and Air Quality Effects," in P. Cutchis, *et al.*, *op. cit.*

If the penalty were fixed in advance, the government could determine the probability of apprehension that was necessary just to deter the average rational potential misfueler. The government could then employ the right number of agents to raise P_A to whatever level would be required to prevent misfueling. The number of agents required would depend upon the number of self-service stations (TOS, and called total misfueling "opportunity stations") that needed to be overseen, the number of hours each agent works per week (AHWW), the number of hours each week the average service station is open for business (SHWW), the percent of time each agent spends at service stations (PTS), and the desired probability of apprehension (P_A^*).[1]

The number of agents required to obtain a desired probability of apprehension (P_A^*) is

$$\text{No. of Agents} = P_A^* \cdot \text{TOS} \cdot \text{SHWW}/\text{AHWW} \cdot \text{PTS} .$$

To calculate the number of agents required we make the following assumptions:

G (gallons at each fueling)	= 12
DIF (price differential)	= 5¢
PEN (penalty)	= $250.

From these assumptions the desired probability of apprehension would be

$$P_A^* = G \cdot \text{DIF}/\text{PEN} = 12 \times .05/250 = .0024 .$$

Suppose further that

SHWW (hours open per week per opportunity station)	= 84
AHWW (hours work per week per agent)	= 40
PTS (percent of time spent at stations)	= 30
TOS (total number of opportunity stations)	= 110,000 .

[1]This methodology is described in slightly more detail in Douglas C. Dacy, "Enforcement Costs of Federal Law Against Misfueling," in P. Cutchis, *et al., ibid.*

The number of agents required would be

No. of Agents = .0024 x 110,000 x 84/40 x 0.8 = 693 .

It is a simple conceptual matter to translate the number of agents into program costs. Suppose that each agent were paid $20,000 per year and that overhead costs (including annualized capital costs) were 100 percent of personnel costs. The total cost of enforcement would be:

Cost of Enforcement = 693 x $20,000 x 2 = $27,720,000 .

This figure is subject to many reservations and should be considered only as a first approximation to be amended when better information is available.

It is important to note that a program costing close to the above estimate of $28 million would not eliminate all misfueling. The basic implied assumption for the proposed methodology is that price differential is the reason for misfueling. Everyone would assess risks differently and the figure of 12 gallons per fueling obviously would not be the same for everyone. These and other factors not included in our analysis assure that enforcement would not prevent all misfueling.[1]

The question of cost-effectiveness remains. While the costs estimated above do not seem excessive in comparison to some other enforcement programs, one must not automatically assume that a federal law against misfueling should be enacted. Misfueling could be limited by other programs, such as an inspection-maintenance program, likely to be more effective with, perhaps, no greater costs.

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[1]This analysis does not consider the other reasons for misfueling. If the benefits from misfueling due to the other motives were greater than those calculated from price differential, more agents would be required. However, much of the shortage and performance-induced misfueling would be prevented since agents would catch misfuelers regardless of motive.

F. PUBLIC INFORMATION PROGRAMS[1]

One option to limit misfueling is based on the assumption that the public would voluntarily reduce their misfueling if people fully understood the harm done to their cars. Thus, a public information program intended to alter behavior is worthy of analysis.

A marketing information program, if it is to be successful, must begin with knowledge about the people to whom the campaign would be directed and, if possible, the motives which underlie the behavior to be encouraged or discouraged. In our analysis we shall assume that price differential, performance, and shortage of unleaded gasoline are the only reasons for misfueling.

To determine the effectiveness of a public education program we divide the population of automobile drivers into three groups. *Frequent misfuelers* are those who use leaded gasoline whenever it is convenient to do so. They are likely to be motivated by the price differential or performance. *Occasional misfuelers* are those who use leaded gasoline only when it is inconvenient not to do so. Rather than going out of their way to properly fuel, they would consider misfueling. Since misfueling is not achieved without prior thought, leading to fuel tank tampering or carrying special apparatus, we assume that there are relatively few occasional misfuelers. The third group of *proper fuelers* consists of people who have not misfueled or who have tried it once or twice but gave up the practice out of conscience or other reasons. This group comprises most motorists. A public information program probably would be most effective if addressed to the occasional misfueler, and is not likely to affect much the "rational economic person" alluded to in the previous section.

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[1]Much of the discussion in this section is based upon Phillip Kotler, *Marketing for Nonprofit Organizations*, Prentice-Hall, Inc. 1975. See particularly Chapter 15 on "Social Marketing."

Any person, regardless of his group, may or may not be aware of the legal, environmental and *true* economic costs (or benefits) of misfueling. To be effective, a public education campaign would have to inform a potential misfueler of some fact that he is unaware of, but which is critical to his decision to change behavior.[1] Some people may not know or may not care how misfueling affects the environment. They might think that the catalytic converter "takes care of everything" and they are likely not to be aware that misfueling poisons their catalytic converters permanently. Advertising reaching these people could be effective.

There is some question whether misfueling is an economically viable activity when total costs are accounted for. It has been pointed out that regular use of leaded gasoline causes more harm to spark plugs, the exhaust system, and the carburetor. Thus, a misfueled car requires more maintenance, especially tune-ups, than one that has been properly fueled. If the price differential were five cents a gallon and a driver used 500 gallons per year, he would save $25 by regularly misfueling. If a tune-up costs $50 and the properly fueled car were tuned-up once a year, misfueling would pay if the practice did not force a tune-up more frequently than eight months. In states like California where law requires an inspection before resale, an additional cost is the price of a new exhaust system; in states such as New Jersey, where pollution control devices are inspected on an annual basis, misfueling is an uneconomical activity. In all other states, probably, it is marginal. In any event, misfueling is not an obvious advantage when all the costs are considered. If this

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[1]Kotler distinguished four kinds of social changes. Some social causes have the limited goal of providing information to create a *cognitive* change. Some other social cause might require an *action* change. The goal would be to spur someone to take a positive action. Another social cause might have as its goal to induce a *behavioral* change, e.g., stop smoking or stop misfueling. Finally, the goal of some campaigns is to induce a *value* change, an attempt to get people to change social values. *Idem.*, pp. 288-296.

is correct, and if misfueling is motivated out of economic consideration, a public education program might be influential in changing the behavior of misfuelers or convincing potential misfuelers not to acquire the practice.

The difficulties in achieving behavior modification are exhibited by the many cases where large expenditures of money have not proven very effective. Some examples are the anti-smoking and anti-drug campaigns. In these cases, the targeted subjects may already have been aware of the potential harmful effects of their behavior. Others may not have been aware of the harmful effects but persist in the practice even after enlightenment. Efforts to convince drivers to use seat belts have not proven to be very effective; indeed, cost-benefit analyses of these efforts tend to show that they are misguided in the first place.[1]

Public relations programs based solely on appeal to one's moral sense (called "moral suasion") have not been very effective. It has been demonstrated, for example, that in many cities voluntary programs intended to stimulate recycling of solid waste by voluntary appeal have failed. By contrast, a program mandated by local ordinance in Hempstead, New York requiring households to place bundles of newspaper on their curbs on designated days had an 80 percent compliance rate.[2] Such failures as we have shown should not necessarily signal that voluntary programs are doomed to failure. Conditions under which they may work are: (1) where the budgetary process has failed to provide funds to carry out a popular will, (2) where policing is difficult and other policy approaches are difficult, and (3) in periods of brief,

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[1]Two studies are cited in Kotler, *idem*, pp. 409-410.

[2]William J. Baumol and Wallace E. Oates, *Economics, Environmental Policy, and the Quality of Life*, Englewood Cliffs: Prentice-Hall, Inc., 1979, pp. 283-289. One especially interested in the subject should read Chapter 13 of this book entitled "Moral Suasion: Uses and Abuses."

unpredictable environmental crises.[1] Only the last of these conditions would seem to apply to the misfueling problem.

A public information program designed to modify behavior is least likely to influence the people to whom it is aimed, for those people have already established bad habits or may already be aware of their consequence. However, if misfueling were illegal, then, by pointing out the potential costs of apprehension, a public information campaign might be successful. But in the present situation, exhortation by the government is not likely to be successful if, from the misfueler's point of view, the economics of the act seem to favor it. Some probably have already made the economic calculation. On the other hand, it could prevent future misfueling and that would be a significant goal of an anti-misfueling campaign.

G. INSPECTION-MAINTENANCE (IM) PROGRAM

When questioned at a recent hearing as to how they would solve the misfueling problem, most oil company executives responded that inspection-maintenance (IM) programs appeared to be most reasonable and effective.[2] An IM program is one which requires motorists to maintain emissions control systems at some specified level of effectiveness. If the system falls below the specified performance level, the motorist would be required to repair it. We shall discuss the technical, economic and political aspects of this approach.

The general rationale for IM programs is that they are an effective means to reduce mobile source emissions from in-use vehicles. With respect to the practice of misfueling, their purpose would be to identify and to enforce maintenance on all vehicles with catalysts rendered inoperable by the introduction

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[1] *Idem*, p. 294.

[2] DoE hearings on mandated price differential, May 10-11, 1979, Washington, D.C.

of leaded fuel. Thus, this policy option can deal with all motives for misfueling. Since any one of several motives may account for misfueling, any policy which has as its goal the removal of a motive (such as mandated price differential) is inherently inefficient: it will not discourage those who misfuel for other reasons. The efficiency of an IM program is independent of guessing correctly the motive(s) of the misfueler. In a sense, IM programs dominate others because they are more general.

In addition, the policy appears to be equitable. If a mandated price differential were imposed, the costs would not be borne by misfuelers, but would likely be divided among refiners, retailers, and motorists properly using leaded gasoline. In contrast, the costs of compliance with an IM program--in this instance, replacing a "poisoned" catalyst--would be borne solely by the person responsible. A mandatory IM program thus has the potential to be both an efficient and an equitable means to reduce the incidence of misfueling.

Although IM programs are already proven to be technically feasible, the equipment required by current inspection procedures cannot diagnose precisely which component of the engine is working improperly. This is because IM programs are designed to identify *all* vehicles which exceed emissions standards, regardless of the cause. Nonetheless, because no other source of emissions violations registers similarly on the diagnostic equipment, trained inspectors should be able to identify an inoperable catalyst by its "imprint."

In the future IM programs may become still more effective by the inclusion of a test developed specifically to identify poisoned catalysts. Several alternate tests have successfully been conducted in EPA laboratories, but none has satisfied the requirement that it be short, nor is the requisite diagnostic equipment commercially available. Notwithstanding the above, however, mandatory IM programs can be a technically feasible solution to the problem of misfueling.

IM programs employing current testing procedures have already proven that they are economically feasible. Indeed, despite substantial variations in capital and recurring costs incurred, IM programs are generally self-supporting: revenues generated by inspection fees cover annual expenses. The inclusion of a test, and the purchase of diagnostic equipment designed specifically to identify poisoned catalysts are unlikely to change this fact. However, if costs to the states do not rise, costs to (some) motorists will. Several states exempt vehicle owners from liability for compliance with emissions standards if repair costs exceed a certain limit--expressed as either an absolute amount or a percentage of the vehicle's book value. These limits are high relative to average repair costs for violations other than misfueling, and thus exempt only a small percentage of those violators; but they are invariably lower (typically, $75-$100) than the cost of replacing a catalytic converter. Consequently, the misfueler can pay the ceiling cost--in essence his fine for purposely misfueling--and with his renewed license or inspection sticker continue to misfuel. Where this provision applies, the effectiveness of an IM program is reduced.

Political feasibility is to some extent a moot question, since certain states will be required by the Clean Air Act Amendments of 1977 to implement mandatory IM programs. However, there are many states, or urban areas within states, that have the latitude to choose. In these states political feasibility is a real issue.

IM programs constitute increased governmental control over the lives of private citizens--during a period when the majority preference is for less, not more, regulation. As a means for reducing the incidence of misfueling they are thus likely to be less politically acceptable than other proposed solutions. Yet there exists a second reason for their relative unacceptability: to be effective for our purposes, anti-tampering laws would have

to become an integral part of IM legislation. Certain states have laws that "prohibit" the operation of vehicles when the pollution control devices have been removed, altered or rendered inoperable. But as long as no strong deterrent to tampering exists, their impact will remain minimal. IM programs could provide that deterrent--paradoxically, by incorporating anti-tampering legislation.

The major obstacle to limiting misfueling through IM programs is that each program requires a separate authority. At first, there probably would be political opposition to the program and political opposition is likely to be very strong at the local level or jurisdiction. The equipment for the program does not appear to be expensive and, if an emissions IM program were added to the on-going safety-check system, the marginal costs would not be high. From an environmental point of view, they would be more effective than a federal law against misfueling and probably their marginal costs would be less than the total costs of enforcing a federal law. Thus, IM programs appear to be "cost effective."

These programs are gaining acceptance in many areas; however, to be most effective there should be no limit placed on repair liability, catalyst tampering should be checked, and the programs should be made a part of some on-going check system to reduce the cost of operating the programs. Also, there is a chance for pay-offs for false certifications, particularly in those states where inspection is left to individual garages. IM programs would have to be policed.

H. GASOLINE RATIONING

One obvious way to relieve the pressure on motorists to misfuel would be to ration gasoline. Gasoline rationing would eliminate or reduce the shortage and could remove that important cause for misfueling. What, perhaps, is not so obvious in regard to this option is that the *manner* of gasoline rationing

may be as important to environmental protection as the cost of rationing in general.[1] In this section we briefly lay out the reasoning behind the previous statement but do not attempt any rigorous analysis of the subject.

Gasoline rationing could take one of the following forms:

(1) Rationing by price
    a) Free market price
    b) Excise tax by government
(2) Rationing with coupons
(3) Rationing by queueing
(4) Rationing through voluntary appeal.

All of the above methods, with the exception of voluntary rationing which might not work at all, eventually could have a desired effect of eliminating the shortage. In the long-run, once market equilibrium were restored between demand and supply, the major issues would be economic efficiency and equity.

Rationing by allowing the free market to adjust price would be efficient. Of the methods mentioned above, it is the only one that would stimulate supply of gasoline. From a purely theoretical point of view, many economists think that it dominates all other methods of rationing. However, the political system does not necessarily endorse all procedures that are most efficient; and in the present situation many would claim that a transference of income away from motorists and to the petroleum production-distribution system is not "equitable." From the point of view of environmental protection, the free market solution would not eliminate the price differential motive for misfueling. In the

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[1]Gasoline rationing is essentially a political problem. Nothing in this section should be construed as an endorsement of this "option" to solve the much easier problem of misfueling. However, should the political system eventually endorse gasoline rationing for other reasons, then the question of the manner of rationing would be important. *Some types of gasoline rationing are more conducive to environmental protection than others* and the motive for including this "option" in this study is to underscore that point.

short-run, the price differential between leaded and unleaded gasoline might increase.

To achieve equilibrium in the gasoline market the government could raise the excise tax by whatever amount was necessary. This method would eliminate the shortage and reduce misfueling. In fact, by fixing different taxes on leaded and unleaded gasoline and, perhaps, subsidizing unleaded gasoline, the price differential and shortage motives for misfueling could be eliminated. There is the question of what the government should do with the revenue raised from the additional tax. This could be rebated back to motorists in some manner considered to be equitable as determined by the political system. While this method has great practical appeal, long-run aggregative consumer welfare under this scheme would be lower than under the free market solution. The reason is that the long-run price of gasoline under the free market solution would be lower. Thus, the attainment of environmental goals under rationing by excise tax would come at some consumer expense in comparison to the free market solution.

Rationing with coupons could achieve virtually the same results as rationing by raising the excise tax on gasoline if the coupons were allowed to be traded in a "white market." This method has the additional feature that, conceivably, the coupons could be tied directly to leaded and unleaded gasoline. However, coupon rationing has a number of administrative difficulties. The major difficulty is the problem of distributing the coupons. If coupons were allowed to circulate freely in a white market, they would take on many aspects of currency. If they were not allowed to be traded, most of the appeal of coupon rationing from an economic point of view would be lost. The most efficient way of distributing the coupons would be through the mail. However, if coupons were a kind of currency, distribution through the mail would be dangerous. For this reason the DoE plan, recently rejected by Congress, proposed to issue ration vouchers that could serve as claim coupons at redemption centers,

i.e., banks. However, this parallel currency system would be very complicated in comparison to alternative systems. Also, administrative costs of coupon rationing would be high and these costs must be considered an additional loss in economic welfare attached to coupon rationing.

Rationing by queueing is probably an effective way to reduce gasoline consumption. The reason is that many people probably would prefer to pay a higher price for gasoline rather than endure the psychic costs of waiting in line and the uncertainty of obtaining gasoline when they want it. If this is true, the price equivalent of the queueing cost is higher than the price necessary to force any given reduction in demand. There are two corollaries to be noted: (1) motorists would drive less under rationing by queueing than under price rationing, and (2) total economic welfare would be lower under rationing by queueing than under price rationing. Some additional gasoline would be wasted due to engine idling while in line, so that total gasoline saving would be less than implied by the above analysis. In addition, rationing by queueing favors ownership of cars that have a long cruising range (large gasoline tanks) rather than cars with high miles per gallon. In the process of achieving supply-demand balance we assume that the frustration due to uncertainty and waiting in line would cause considerable misfueling leading to catalyst destruction. Rationing by queueing appears to be the worst possible option with respect to environmental protection.

In summary, the most efficient method of rationing appears, at the present time, to be politically impractical, whereas rationing by queueing requires no political action at all. Rationing by queueing in the summer of 1979 occurred largely by default; yet it probably is the worst method with regard to the environmental protection and economic welfare.

I. BLENDING MATERIALS TO INCREASE SUPPLY OF UNLEADED GASOLINE

One possible way to ease the problem of misfueling is to increase the supply of unleaded gasoline; this will make it more available and work in the direction of reducing the price differential. The moves taken by the EPA to suspend the ban on MMT and to allow more lead in leaded gasoline should serve to increase the supply of unleaded gasoline for the period they are in effect.[1] However, those moves are not sufficient to ensure an adequate supply of unleaded gasoline, even in the intermediate-term period.

Before the removal of the ban on MMT, the substance had market outlets in Canada as an additive for unleaded gasoline and was used as a combustion material in heating oil. There was some excess capacity but not enough to fill the need in the U.S. for all unleaded gasoline if MMT were used in concentrations of 1/32 gram Mn/gallon of gasoline. Ethyl Corporation has estimated that MMT capacity is sufficient to fill about two-thirds of its potential demand.[2] To fully meet potential demand a new plant would be required and its completion could not be reasonably expected before eighteen months. Of course, it is not likely that investment for such a plant will be forthcoming unless there is a clear signal that MMT will be permanently approved. Obviously, the issue of MMT is long-term and must be considered in that context.

For the intermediate-term there are a few blending fuels that have received much publicity. These are methanol, ethanol, tertiary butyl alcohol (TBA), and methyl tertiary butyl ether (MTBE). Actually these materials should not be considered separately. Ethanol is being used directly as a fuel in blend with gasoline to produce "gasohol." The preferred use of methanol

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[1] See Sections B and C in Chapter II above. Using more lead in leaded gasoline allows the producers to use lower clear octane thereby freeing up minimal feedstocks for unleaded gasoline.

[2] Data supplied by Mr. Howard Hesselberg, a Vice-President of the Ethyl Corporation.

is in chemical combination with isobutylene or possibly isoamylene to form MTBE or tertiary amyl methyl ether (TAME).

Our survey of these materials[1] indicates that none promises to give significant relief to the intermediate-term unleaded gasoline shortage problem. Gasohol has received much political attention. Gasohol can compete primarily because it is highly subsidized, about $18 a barrel for ethanol. The subsidy is due to the exemption gasohol receives from federal excise taxes and, in some states, relief from state excise taxes. Thus, the one gallon of ethanol is exempt and the nine gallons of gasoline required to make 10 gallons of gasohol are also exempt. With a subsidy as high as $18 a barrel, other options such as synthetic fuels would look relatively better than they do at present.

Some intermediate-term relief can be expected from using MTBE as a blending material. MTBE capacity in 1980 is expected to be only about 1.3 billion pounds. This relatively low capacity would limit the potential increase in unleaded gasoline production to about 0.7 percent over the next one to two years or about 20,000 b/d. However, even this volume of production could easily overstate the actual net amount of increase. The reason is that MTBE might be used to replace toluene so that the latter could be used in petrochemicals.

We conclude that any major increase in unleaded gasoline production will have to come from additional reforming capacity, or the further use of MMT if, after further testing and analysis, that is found not to be excessively environmentally harmful.

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[1]Robert C. Oliver, "Use of Additives and Blending Agents to Increase the Unleaded Gasoline Supply," in P. Cutchis, *et al.*, *op. cit.*

Note 1

NOTES ON THE REVERSIBILITY OF THE PRICE DIFFERENTIAL MISFUELING FUNCTION

In Section 2A (page 8) we postulate the existence of a price differential misfueling function, $M = a + D^{\beta}$. This function is assumed to be reversible: motorists will switch from unleaded to leaded gasoline in a specified quantity with a rise in the price differential between the two and will reswitch to unleaded gasoline by the same amount if the price differential is restored to its previous level. Some reviewers have questioned the validity of this assumption.

Under what conditions would this assumed symmetrical behavior be inappropriate? In general, something in the switcher's character (tastes) would have to change or he would have to gain new information in the process of switching. For example, suppose that a switcher felt "guilt" at the time of first switching but after misfueling several times his sense of guilt disappeared or that he gained new information from switching that his car performed better on leaded than unleaded gasoline. In either case a function representing reswitching would be less steep than the function representing first switching.

While an irreversible function is possible, it is not likely in our opinion. We assume that each person knows his essential character (tastes) and that no new information is gained from switching. Given these assumptions, each person acts rationally (consistently). Knowing one's own tastes is a major assumption in almost all economic actions. Consider the following analogy taken from demand theory. Suppose that a relative rise in the price of beef with respect to the price

of pork induces a person to switch from beef to pork. Will this same person return to the original quantities of beef and pork purchased if the relative price of beef falls back to its original level? The answer is yes, provided that the tastes for beef and pork remain unchanged.

With respect to misfueling, it is possible that people's tastes will change. This is unchartered territory so the analyst must replace knowledge with assumptions. In the absence of information to the contrary, we think our assumptions on reversibility have a strong claim because of its similarity with many economic functions about which information is available.

DERIVATION OF THE "CRITICAL RATIO" FOR MMT USAGE

Let HC_1 = Total increase in HC emissions due to misfueling

h_1 = Increase in HC emissions in grams per mile for each car misfueled

A = Average miles driven per car

$MR(S)$ = Misfueling rate due to shortage

N = Number of cars with catalytic converters

HC_2 = Total increase in HC emissions due to use of MMT

h_2 = Increase in HC emissions in grams per mile for each car using MMT-boosted gasoline

$$HC_1 = h_1 \cdot MR(S) \, [N \cdot A]$$

$$HC_2 = h_2 \, [N \cdot A]$$

Hydrocarbon emissions would be equal when $HC_1 = HC_2$ or when

$$MR(S) = h_2/h_1 \, .$$

When $MR(S) > h_2/h_1$, emissions due to misfueling would be greater than those due to MMT. When $MR(S) < h_2/h_1$, emissions due to misfueling would be less than those due to MMT. Thus, h_2/h_1 is the "critical ratio."

GASOLINE SUPPLY AND DEMAND ESTIMATES, 1978-1981

Table B-1 presents estimates on supply and demand for gasoline for the period 1978-1981. The variation in supply estimates is due, in large part, to assumptions on capacity utilization. The range of capacity utilization assumed for deriving the supply numbers in the table is 90-92.7 percent. The National Petroleum Council (NPC) figures were based on an extensive survey and, therefore, appear to be the best available. However, one might question the 92.7 percent utilization rate used to obtain the NPC estimates.

The balance between supply and demand is critically dependent upon assumptions regarding capacity utilization and whether one accepts the high or low estimate of demand. For 1980 the figures in Table B-2 can be derived. Given those possible combinations shown in the table, the worst situation would be a daily gasoline deficit of 678,000 barrels, whereas the best daily outcome would be a gasoline surplus of 144,000 barrels. The figures in the table are split evenly with positive and negative signs.

The Department of Energy's study[1] assumes imports of 300,000 b/d but does not specify whether it is leaded or unleaded gasoline. The study by the Petroleum Industry Research Foundation, Inc. states that probably no more than 50,000 b/d of unleaded

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[1]Department of Energy, *Motor Gasoline Deregulation and The Gasoline Tilt* (Final Environmental Impact Statement), Vol. 1, January 1979, Appendix F, Table 6, p. 35.

Table B-1. GASOLINE SUPPLY AND DEMAND ESTIMATES, 1978-1981
(Thousand barrels per day)

	1978	1979	1980	1981
DEMAND				
DoE[a] Low			7,585	
High			7,962	
PIRINC[b]	7,390	7,527	7,561	7,584
(Unleaded %)	(34)	(42)	(50)	(57)
Unleaded	2,513	3,161	3,781	4,323
SUPPLY				
DoE[c] Case C			7,284	
Case F			7,662	
Imports			300	
PIRINC[d]	7,390			7,862
NPC[e]		7,402	7,653	7,782

Sources:

[a]Department of Energy, *Motor Gasoline Deregulation and The Gasoline Tilt* (Final Environmental Impact Statement), Vol. 1, January 1979, Appendix F, Table 6, p. 35.

[b]Petroleum Industry Research Foundation, Inc., "Motor Gasoline: An Outlook for Supply and Demand to 1981," March 1979, p. 4.

[c]Department of Energy, *op. cit.*, pp. 34-35. Case C assumes 92 percent capacity utilization, use of MMT, octane sharing in leaded gasoline, no reduction in pool octane for unleaded and pool lead average .59 g/gal. Case F assumes 92 percent capacity utilization, no MMT, no octane sharing in leaded gasoline, no reduction in octane pool in unleaded, and lead pool average 1.20 g/gal.

[d]Petroleum Industry Research Foundation, Inc., *op. cit.*, p. 7. These figures are derived from the capacity data cited in the study assuming a 90 percent capacity utilization rate and 48 percent share to gasoline. This last figure is implied from other data in the study.

[e]Draft study by National Petroleum Council (NPC) reported as "U.S. Refiners See Slow Capacity Buildup," *The Oil and Gas Journal*, June 4, 1979, pp. 53-55. The figures in the above table are mid-year interpolations based on data reported by the NPC applicable to January 1978, January 1980, and January 1982. See Table 2 in *ibid.*

Table B-2. GASOLINE SURPLUSES (+) AND DEFICITS (-) IN 1980 IMPLIED IN VARIOUS POSSIBLE SUPPLY AND DEMAND COMBINATIONS

(Thousand barrels per day)

Supply Estimate \ Demand Estimate	DoE (Low)	DoE (High)	PIRINC
DoE (Case C)	-301	-678	-277
DoE (Case F)	77	-300	101
PIRINC	120[a]	-257[a]	144[a]
NPC	68	-309	92

[a]Assumes that PIRINC supply estimate for 1980 would be two percent less than the estimate for 1981. This is approximately the relationship in the NPC figures in Table B-1.

gasoline will be imported.[1] With some importation of gasoline, it appears that the overall supply-demand situation in 1980 (and probably 1981) will be close to balance if adverse events do not occur.

From the EPA's point of view the situation might appear more difficult than the figures indicate. The question is whether *unleaded* gasoline production will increase by 35-40 percent as it must to keep even with demand. The answer to this question depends in part upon whether the tendency to increase octane in unleaded gasoline can be arrested. In the past the automobile manufacturers have been designing engines requiring higher octane gasoline to meet their mandated miles per gallon standards. Octane is an obstacle to increasing unleaded gasoline supply. For example, 53 percent of total production could be unleaded in 1980 if the octane remained at 89 (R+M)/2, whereas

[1]Petroleum Industry Research Foundation, Inc., "Motor Gasoline: An Outlook for Supply and Demand to 1981," March 1979, p. 13.

if the octane were to rise to 90, only 38 percent of total production could be in the form of unleaded gasoline.[1] Even if these quoted estimates were slightly exaggerated, the point is clear: supply/demand balance for unleaded gasoline in the intermediate-term depends critically upon stopping the octane creep in unleaded gasoline.

[1]National Petroleum Council (NPC) reported as "U.S. Refiners See Slow Capacity Buildup," *The Oil and Gas Journal*, June 4, 1979, p. 54.